TMO TECHNOLOGY DEVELOPMENT PLAN

Work Area Name:

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OBJECTIVE:

Reduce the cost of long duration cruise missions and decrease the loading on DSN antennas by creating a new approach to operations that reduces frequency of contact and volume of downlinked engineering telemetry.

GOALS and SIGNIFICANCE:

The primary goal of this work area is to develop or coordinate development of all of the components necessary to flight demonstrate beacon monitor operations on the New Millennium Program Deep Space One (DS1) mission and to implement a capability for future JPL missions. This work area develops the baseline operational concept for missions that will use beacon monitor operations. New approaches to operations are necessary given the cost constrained mission environment. Moreover, the NASA administrator sees developing new operations approaches critical to the success of the new NASA. The work element also funds development of flight software for selecting beacon tones and for summarizing spacecraft engineering data. Onboard summarization is necessary when the frequency of tracking is reduced and to reduce the time required to process and analyze engineering telemetry. Ground software is being developed to process tone messages and to display/visualize summary data. A tone monitoring system enables the NASA vision of "darkening the skies" with small spacecraft. Implementing beacon operations can also save upwards of $3M/yr on planned missions to Europa and Pluto. A tone detector is being developed through this work area to receive beacon tones. This system is portable to multiple antennas but will be used at DSS26 to receive beacon tone signals during the DS1 mission. Coordination with a TMOD task for implementing advanced scheduling methods for DSN antennas is also ongoing. Such scheduling approaches are essential in order for DSN support of beacon monitor operations to be viable.

PRODUCTS:

Key products include multi-mission flight software for tone selection and onboard engineering data summarization, ground hardware for detecting beacon tones, ground software for summary data visualization, detailed operations procedures and concept descriptions, and lessons learned/experiment results from the DS1 mission flight validation experience. The primary users initially are DS1 and the Ice & Fire Programs. The planned evolutionary path is to migrate DS1 flight software into the X2000 development effort. Although this has already begun to some degree with early prototypes, flight ready DS1 prototypes will be passed to X2000 in FY98. Other missions, including SIRTF, Champollion, Genesis, Contour, and other upcoming missions are suitable for beacon operations. Team members from SIRTF and Champollion have expressed an interest in using technology. Capabilities will be delivered to these potential new mission customers as required. This task also funds development of an operational concept and protoype for earth orbiting spacecraft through a contract with Stanford University.

DESCRIPTION:

There are at least an order of magnitude more missions in development today than there were ten years ago. The trend towards flying many more missions is real and the development of new approaches to mission operations is imperative in order to meet NASA's vision for the future. The desire for new operations approaches has come from the top-down (Goldin) and from the bottom-up (mission pre-projects). Beacon monitor operations grew out of this new environment and is baselined

for use on upcoming NASA missions. This work area develops the beacon technology for initial flight validation on DS1 and provides some of the technical background to help TMOD decide if it should provide a standard service for these types of missions in the future. If TMOD does not provide this service, Ice & Fire (and possibly other) missions will likely look outside of TMOD for beacon monitor support. Regardless of whether TMOD supports these missions, it is prudent to perform early flight validation and to gain operational experience before beacon operations is designed into high-profile science missions.

The current tone system is proving to be the most effective means of transmitting beacon signals. The DS1 experience is showing the there is enough link margin to support the tone system for all of the prime mission, while the link for telemetry using the LGA can only be maintained at the mission onset. Since DS1 cannot thrust and point the HGA to earth, sending tones using the LGA is the only viable option for beacon signaling. As we move more into shoebox-sized 2nd generation X2000 spacecraft, small antennas, low power, and solar electric propulsion systems are all factors that make a sub-carrier tone system (rather than a BPSK-based system) a more viable option.

The tone detector being developed has a large performance advantage over the existing DSN receiver. For the very-low-data-rate application that is inherent to the beacon monitoring concept, the noncoherent tone detector has 10 dB performance advantage over the coherent BPSK receiver. The tone detector back-end system is portable to other antennas and the current unit can serve as a prototype for building additional units to serve other antennas.

The basic vision for beacon monitor flight software is that it needs to be reusable and extensible. In order to accomplish this, it is being developed and integrated into the DS1 architecture and the X2000/ Ice & Fire architectures simultaneously. By making deliveries to real development programs, the beacon development team stays current on software architectures, platforms, and development paradigms employed on these programs. The current functionality of the summarization software is meant to be a starting point in an aggressive roadmap to develop summarization systems for future missions. Mission customers will be able to choose the summarization techniques and level of software technology (and associated risk) for their given mission.

Future missions will be pressured to reduce the frequency of contact and to have very limited or on-demand operations teams. Since weekly telemetry tracking during routine operations is becoming the norm on upcoming missions, a beacon signaling system can be used to better ensure mission success by providing more frequent assurance that the spacecraft is OK. Missions using solar electric propulsion benefit because the tone system provides daily assurance that the continuous thrust of the engines has not stopped. Waiting one week or even a few days in between telemetry passes would reduce the margin in the mission timeline, possibly threatening the mission. In the more general sense, beacon monitor operations is a method for allowing the spacecraft to determine when ground contact is required. The beacon system affords a great deal of flexibility in how it is implemented throughout a mission. Yet, it imposes a discipline on flight projects that will a foster acceptance of increasing levels of autonomy. In the long term, this change is necessary to truly “darken the skies” with autonomous spacecraft early in the next century.

Further out, the capabilities being developed under this work area can help pave the way for new mission concepts. The tone system can be extended to notify the ground that the spacecraft has detected/processed important science data. An example might be automated detection of ice flows on Europa as detected by a Europa orbiting spacecraft. Other applications include using the tone detector to receive signals from future Mars rovers. As NASA moves into coordinated fleets of spacecraft, tone signaling could become useful to coordinate fleet activities (spacecraft-spacecraft link) or to facilitate ground interaction with a single spacecraft in the fleet.

DELIVERABLES:

Tone Detector Deliverables:

A completed tone detector	10/97
Compatibility test	12/97
Tone detection demo	2/98
A tone detection and message delivery system capable of schedule-driven, automated operations.	3/98

Report documenting the results of the experiment during the checkout phase	9/98

Flight Software Deliverables:

Flight software for adaptive alarm thresholds	10//97
Flight software delivered to DS-1 project	12/97
Beacon monitoring concept for optical communication	6/98
Software effectiveness evaluations during DS1 ops	7/98- 9/98
Autonomy Lab Demo	6/98
End-of-year Demo	9/98
Monthly Web-based status reports from Stanford	monthly
End-of-year report from Stanford	9/98
FY98 Lessons Learned document (replaces annual report)	9/98
Operational Assessments/ DS-1 experiment results,	12/98, 3/99, 6/99
Post-launch software updates (if required)	FY99
FY99 Lessons Learned document (replaces annual report)	9/99

RESOURCE REQUIREMENTS BY WORK UNIT:

	JPL Account #	FY98	FY99	FY00	FY01	FY02	FY03
Beacon Tone Detector	***412-41208***	205	90				
Beacon Flight SW	***586-WC501***	150	45				
Total		355	135				
Total Workforce		2.1	0.8				

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Beacon Mode Signal Detection

WORK UNIT IN WHICH FUNDED: Beacon Mode Signal Detection , 412-41208-0-3310

WORK AREA:

BRIEF TECHNICAL SUMMARY:

The proposed work is to support the Beacon Monitor Experiment (BMOX), which will be conducted on the first New Millennium Spacecraft (DS1) to validate the key technologies and the operational performance of a new spacecraft monitoring concept. The role of this work unit is in the areas of telecom system engineering and ground system design. The objectives of this work unit are to : (1) develop a tone detector, (2) provide an automated tone detection and message delivery system, (3) plan and conduct the experiment as a BMOX team member, and (4) perform data analysis and assess the operational performance and benefits of the monitoring concept and signaling/detection scheme.

This emphasis of this work unit is on the tone detector development, experiment planning and coordination, and the design of the ground system for the experiment. To provide a low-cost, automated tone detection and message delivery system, this work unit will make use of existing DSN resources and leverage on the station automation technologies being developed by the Deep Space Terminal (DS-T) task. An agreement has been secured with TMOD managers and the DS-T task manager to insure equipment availability.

JUSTIFICATION AND BENEFITS:

Beacon monitoring is a new approach in spacecraft monitoring. Deep space missions traditionally schedule ground antennas to receive spacecraft engineering data up to several times a week for monitoring purposes. This new monitoring concept can reduce the monitoring time to a few minutes a day and full engineering data once every several weeks. This can result in significant cost savings for future flight projects and reduce the loading on the DSN antennas. In addition, the tone detector being developed has a large performance advantage over the existing DSN receiver. For the very-low-data-rate application that is inherent to the beacon monitoring concept, the noncoherent tone detector has 10 dB performance advantage over the coherent BPSK receiver.

This new monitoring approach is being considered for use on upcoming missions to Europa and Pluto and possibly other missions.

APPROACH AND PLAN:

The work described in this proposal was initiated in FY97 to support the Beacon Monitor Experiment (BMOX). This work unit is responsible in the areas of telecom system engineering, detection algorithm design, detection software, data collection and analysis, and assessment of performance limits and operational benefits. The work will be performed by sec. 331 and 335. Section 331 will have overall responsibility of this work unit, will participate in all BMOX activities as a team member, and will interface with DS1. Section 335 will be responsible for the development and operation of the tone detector. An automated tone detection and message delivery system will be implemented to conduct the experiment. This system will utilize DSS-26, the automation technologies and equipment being developed by the DS-T task, and the tone detector. The tone detector will have two parts: the signal detection software that will be developed by this work unit, and the Full Spectrum Recorder (FSR) procured by TMOD for DSS-13. The tone detector will be installed at DSS-26 and interfaced with the DS-T equipment to provide an automated tone detection and message delivery system. The integrated system will be tested prior to launch of the DS-1 spacecraft.

For FY98, the following tasks are planned:

(1) Update the experiment plan to incorporate changes in mission plan.

(2) Verify space-ground compatibility.

Conduct tests to verify space-ground compatibility for tone generation, transmission, and detection, using real-time or recorded data from DS-1 during subsystem or system tests (TDL/ATLO/Thermal Vac).

(3) Complete tone detector development.
Complete the tone development. Interface the tone detector with the DS-T computer and conduct tests to verify software interface and communication protocol needed for file transfer and automated operations.

(4) Implement and test the tone detection and message delivery system.
Install the tone detector at DSS-26. Verify hardware and software interfaces with station equipment and the DS-T equipment. Conduct tests to verify that tone detection and message delivery system is capable of automated operations. Give a demo to satisfy DS-1's requirements.

(4) Conduct experiments, collect data, and perform data analysis.

DELIVERABLES:

A completed tone detector	10/97
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Report documenting the results of the experiment during the checkout phase	9/98

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Completion
Funding ($K)	145	205	90			440
Workforce (WY)	0.8	1.1	0.5			2.4
Co-funding ($K)						0
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Beacon Monitor Flight Software,

WORK UNIT IN WHICH FUNDED: Beacon Monitor Flight Software, 586-WC501-0-3950

WORK AREA: Beacon Operations

BRIEF TECHNICAL SUMMARY:

This task funds the third, and most crucial year of developing flight software for a new mission operations technology called beacon monitor operations. The reusable flight software modules perform two primary functions: tone selection and engineering data summarization. This task also funds evolution of the basic operational concept for future JPL missions and multi-disciplinary and multi-organizational coordination among the other components (flight and ground) of this technology. Stanford University Space Systems Development Laboratory is also funded to investigate adaptations of the beacon concept and flight software to earth orbiter spacecraft and is planning to demonstrate their approach on the Sapphire mission.

Tone selection software maps spacecraft state to "urgency of ground response" and commands the transponder to send one of four possible beacon tone signals. Summarization software consists of a suite of techniques for creating concise summaries of what has occurred onboard the spacecraft since the last telemetry pass. Together these components provide a capability for reducing the frequency of tracking and reducing the amount of analysis time required when tracking is required.

The summary software design leverages priority-based telemetry management schemes to collect (and prioritize) data for downlink. Several transforms of the data (high, low, average, first derivative, second derivative) are computed on individual engineering channels. If an alarm limit is exceeded onboard the spacecraft, an "episode" is generated which contains the culprit and causally related sensors for the time period just before until just after the time in which the episode occurred. Nominal data is summarized by capturing high, low, and average values at a specified sample rate (which scales with mission distance). Special performance data, similar to episode data, can be captured around the time of events of a priori importance to ground operators. Finally, high-level statistics on spacecraft state, number of alarm limit crossings and other data are computed to help set the context for each summary.

In addition to using hard-coded (traditional) alarm thresholds to identify episodes, an AI-based technique is also being implemented as part of the summary software. With this method, alarm limit functions are developed by training a ground-based neural network. These functions are uploaded to the spacecraft to provide tighter, more concise alarm limits. The neural net could reside onboard for future missions to increase cost savings further.

Flight-ready prototypes are approximately 70% complete and are being delivered to the DS-1 Beacon Monitor Operations Experiment (BMOX) for integration. The remainder of flight software development will be completed in this year along with continued evolution of the operational concept. In addition to these activities, an operational concept for an optical beacon system for missions using optical communication will be developed and new techniques for onboard summarization will be investigated.

JUSTIFICATION AND BENEFITS:

Early flight validation of the beacon monitor operational concept and flight software components are required by Pluto and Europa missions. This task funds development of this new technology and delivery of flight software to meet this requirement through a new technology experiment on the DS-1 mission.

Return on Investment

Beacon operations provides a means for substantial reductions in operations staffing and DSN loading. For a mission to Pluto, a cost savings of approx. $3 million per year has been estimated, which would result in $21 million in

savings if the technology was used for 7 years of cruise. Missions to Europa or other Deep Space missions would reap similar savings. Beacon monitor can also provide major advantages to the DSN which needs to reduce the loading each spacecraft imparts in order to support more missions with existing ground resources.

The technology is likely also to be valuable for cost savings on DS-1 extended mission and may help justify extended mission to NASA sponsors. Also on DS-1, there is a need to use the tone system to quickly inform ground staff if solar electric propulsion has shut-off between scheduled bi-weekly telemetry passes. It is important on DS-1 to preserve as much margin as possible in the thrust profile. The beacon system can help do this.

Mission Customers

- Pluto mission
- Europa mission
- Deep Space One
- Future New Millennium Program missions
- Investigating SIRTF, Contour, Genesis
- Components such as data summarization are available to all future missions
- Citizen Explorer (University of Colorado)
- Sapphire Mission (Stanford University)
- Other deep space missions

First Users

- Contributions to Pluto Express testbedding efforts have already been made
- The technology is currently being delivered for flight validated on Deep Space One
- X2000 is planning to demonstrate data summarization in FY97 and would like to receive our latest prototypes for testbed demos in FY98

APPROACH AND PLAN:

Plan Overview

1. Continue flight software development, delivering flight-ready modules to DS-1 for integration.
2. Continue producing demos that highlight flight software functionality.
3. Continue working with DS-1 and other mission customers to assess the viability of beacon monitor operations, technology validation objectives, operational effectiveness assessments.
4. Fund development of ground system display tools to the degree required to assess performance of beacon monitor flight software modules.
5. Continue funding Stanford University's efforts to adapt the beacon monitor operational concept to earth orbiting spacecraft. Continue sharing flight software design information and products as required.
6. Continue coordinating technology development efforts with other tasks at JPL as appropriate (see Teaming Arrangements)

Technology Transfer to Mission Customers

Technology transfer has already begun by providing design information and prototypes to DS-1, Pluto Express, X2000, Sapphire (Stanford), Data Chaser (U. Colorado), and others. This task provides a firm commitment to DS-1 to develop software that it can easily incorporate into the flight software architecture.

Teaming Arrangement

- Demand Access Automation

- DS-1 BMOX funding
- JPL Autonomy Lab
- TMOD DS-T task (funds transition of DSS-26 to an experimental station)
- TMOD Beacon Signal Detector task
- Section 341 research into summarization for flight software monitoring
- Section 395 work in advanced monitoring

DELIVERABLES:

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RESOURCE REQUIREMENTS:

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)	285 k	150 k	45 k		0
Workforce (WY)	2.5	1	0.3		3.8
Co-funding ($K)	250 k	200 k			0
Projected Savings ($K)			100 k	350 k	0